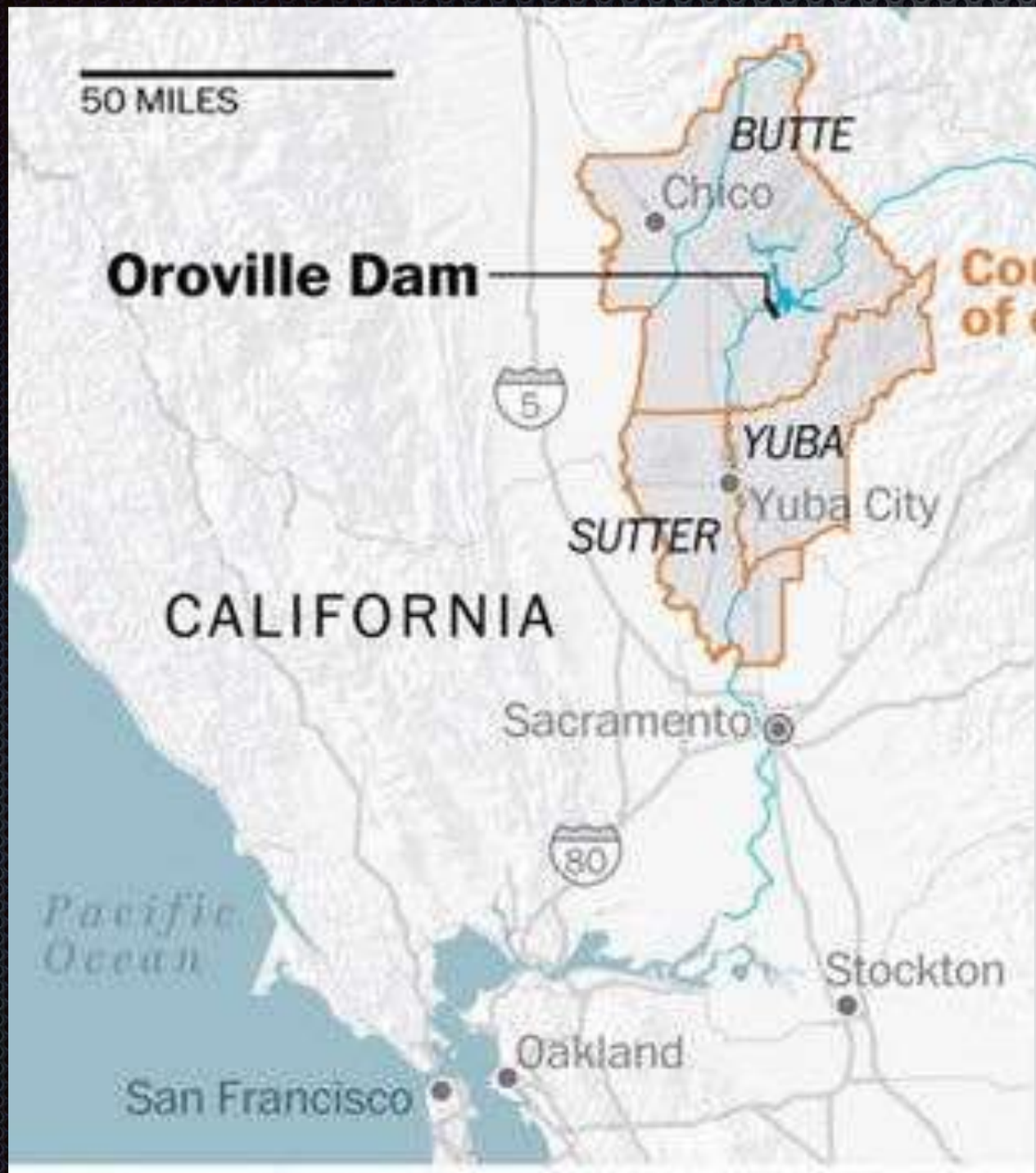
Geospatial Aspects of Emergency Response
Oroville Dam Spillway

September 6, 2017 NGAC

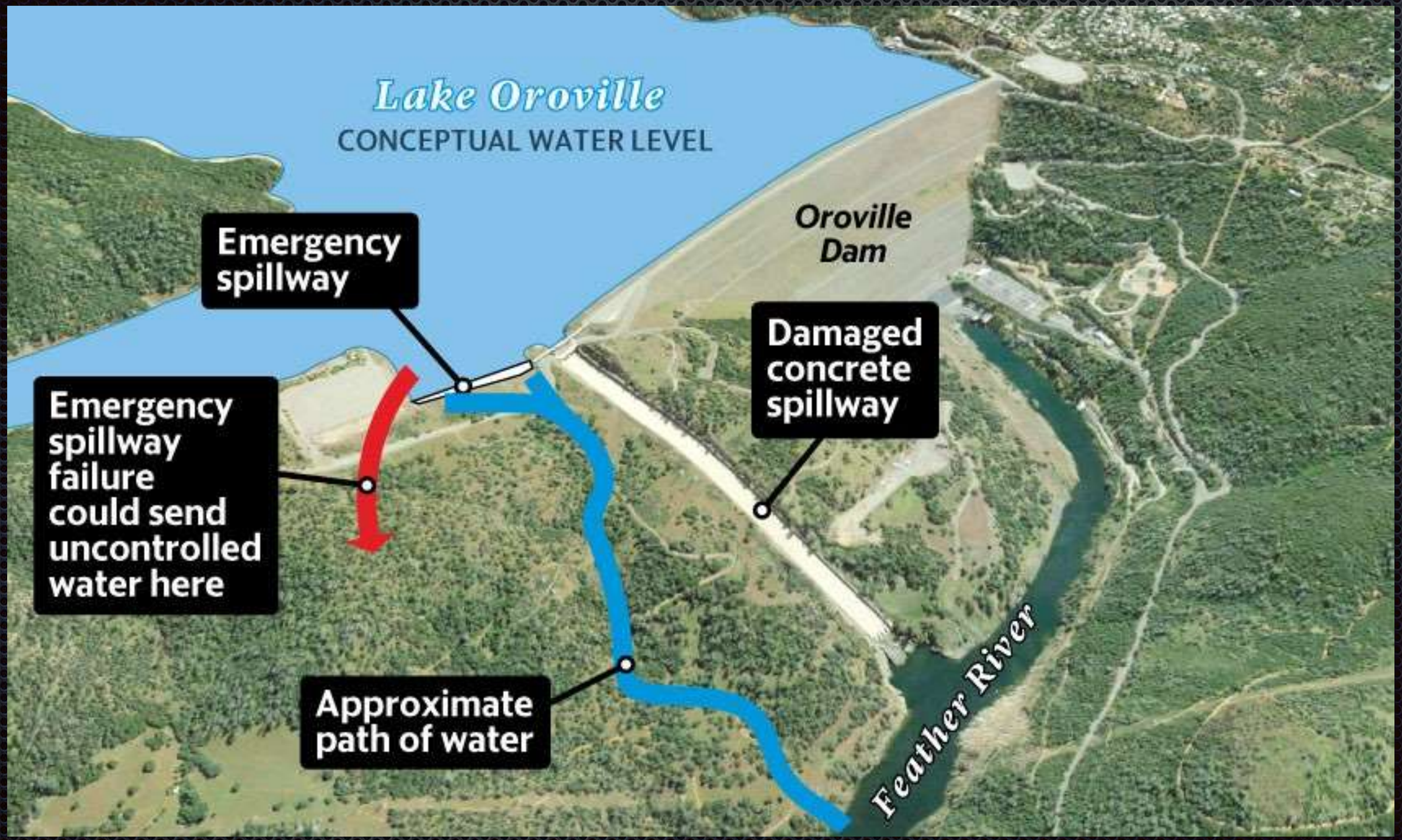
Xavier Irias, Director of Engineering and Construction

Oroville Dam Background Info



Oroville Dam Facts:

- **770’ high**
- **Earthen dam**
- **Built in 1967**
- **3.5×10^6 ac-ft**


Lake Oroville
CONCEPTUAL WATER LEVEL
Oroville Dam
Emergency spillway
Damaged concrete spillway
Emergency spillway failure could send uncontrolled water here
Approximate path of water
Feather River

Oroville Spillway Crisis

Oroville Spillway Crisis

FEB 11

Emergency spillway use begins

FEB 12

Evacuation Order for 188,000 people

FEB 13

Emergency repairs begin

FEB 14

Lake levels recede. Evacuation order modified to advisory

❶ February 7: As water releases from the flood control spillway ramp up to 54,500 cubic feet per second (cfs), in anticipation of inflows expected from rainfall, DWR employees notice an unusual flow pattern. Spillway flows stop for investigation. Engineers find large area of concrete erosion.

❷ February 8: DWR begins ongoing consultation with FERC and other dam safety agencies. DWR runs test flows down the damaged spillway, monitoring further erosion, and prepares for possible use of emergency spillway. 24/7 emergency interagency operations centers activate to study and implement response to flood control spillway and related structures, with careful study of weather forecasts.

❸ February 11: Inflow to Lake Oroville brings lake level above 901 feet. This engages the emergency spillway for the first time in the history of the facility.

❹ February 12: Anticipated erosion begins to progress faster than expected at the base of the emergency spillway. The Butte County Sheriff's Office issues mandatory evacuation orders for the Oroville area. To ease pressure on the emergency spillway, the flood control spillway outflow is increased to 100,000 cfs. After several hours, inflows decrease and overflow stops at the emergency spillway. Erosion to the emergency spillway hillside is assessed.

❺ February 13: DWR crews begin working around the clock to repair the emergency spillway. Evacuation orders remain in effect.

❻ February 14: As the lake level continues to drop, the mandatory evacuation order is modified to an evacuation warning. Crews continue working around the clock to repair the emergency spillway.
An elevation of 850' is targeted for lake level.

To Engineer is Human

Johnstown, PA May 31, 1889
2,300 killed
Spillway capacity inadequate
Strict liability doctrine spawned

St. Francis Dam, CA March 12, 1928
400-600 killed
Rock abutments flawed
CA dam safety agency DSOD created
Licensing required for civil engineers

Teton Dam, Idaho
June 5, 1976
11 people killed, $2B damage
Piping failure
National dam safety program created

That’s All? Just 3 Failures? Hardly.

Austin Dam, Sept 30, 1890
78 killed

Mill River Dam
June 9, 1874
139 killed

Walnut Grove Dam, AZ 1890
70-100+ killed

Spaulding Pond Dam,
Norwich CT, March 1963
6 killed, bad design and maintenance

Baldwin Hills Dam, CA
Dec, 1963
5 killed
Ground subsidence

Abundance of lessons to be learned…

Buffalo Creek Dam Feb 26, 1972
125 killed

Canyon Lake Dam, SD June 9, 1972
238 killed

Lawn Lake Dam 1982
3 killed

Kelly Barnes Dam,
Georgia 1977
39 killed
Spillway problems, slump on dam face

Swift Dam, Montana June 1964
28 killed

Modern dams have failed too

Johnstown PA, 1977
88 killed
Inadequate spillway

"We investigated this dam in the '60s. Its deficiencies were recognized and reports prepared for modification, but for various reasons, over a period of one-and-a-half decades, remedial steps or new construction was not taken.

If the dam had been upgraded in accordance with today's prudent engineering practice, the dam would have been able to store and/or pass the storm."

--Investigating engineer

Taum Sauk, 2005
0 killed
Designed with no spillway

Ka Loko Dam, Hawaii, March 2006
7 killed
Bad maintenance, illegal mods

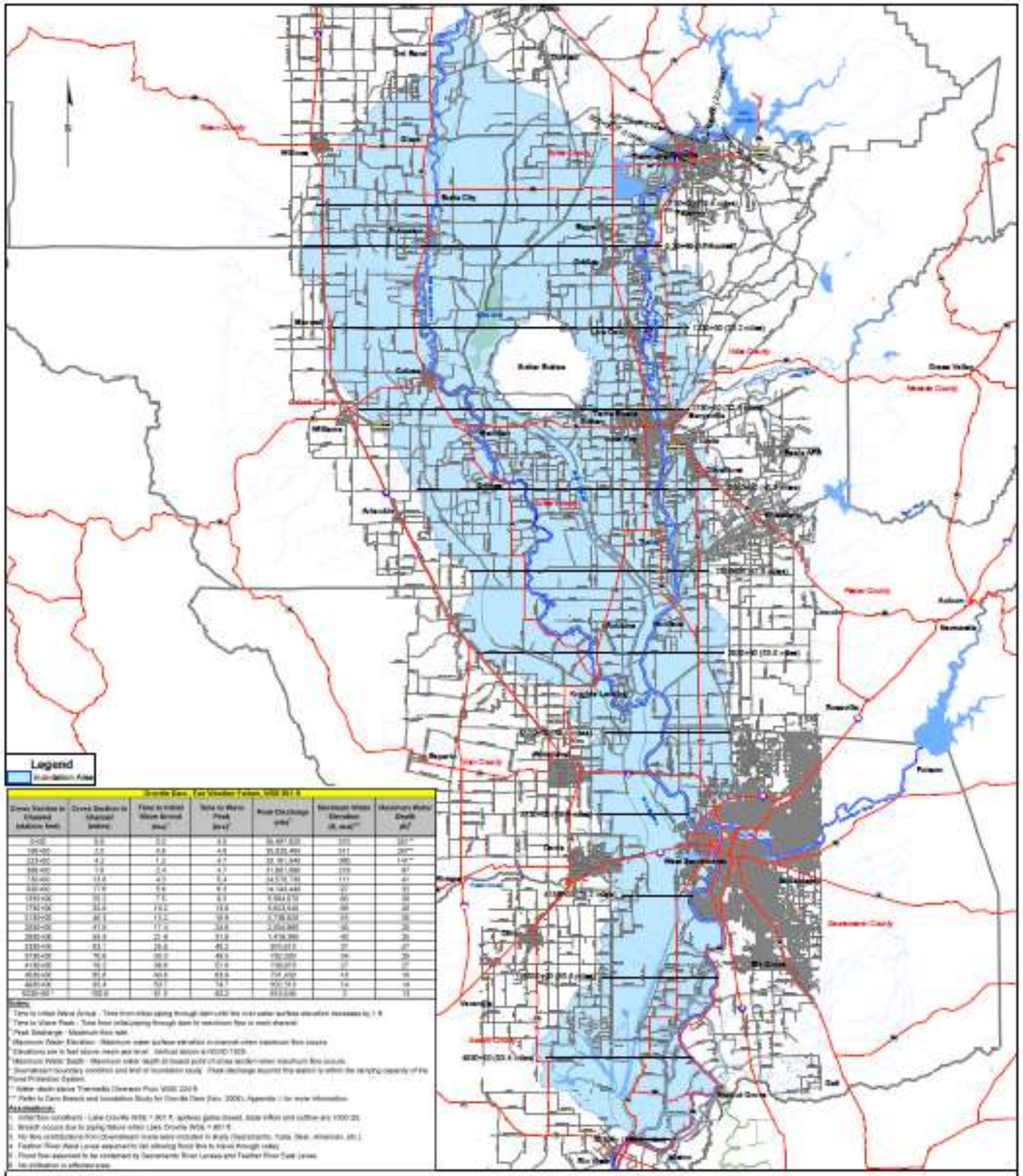
And Some Near Misses

February 9, 1971 Lower van Norman Dam, CA
80,000 people evacuated when dam liquefied in EQ

2015 Lewisville Lake Dam, TX
431K people at risk, volume 125x that of Johnstown
Risks identified 2005, not disclosed to public till late 2015 when winter storms brought dam to brink of failure.

Dam Safety Program Elements

- Dam monitoring, followed by remediation of any issues
- Dam studies and, as appropriate, capital projects to address study findings
- Training
- Emergency response planning
  - **Inundation maps**
  - Plans
  - Exercises



Gross Section to Channel Inflow (mile)	Gross Section to Channel (miles)	Time to Initial Wave Arrival (hrs)*	Time to Wave Peak (hrs)*	Peak Discharge (cfs)*	Maximum Water Elevation (ft. msl)**	Maximum Water Depth (ft)*
0+00	0.0	0.0	4.5	36,487,630	331	101*
095+00	3.8	0.8	4.5	35,535,460	341	99**
223+00	4.2	1.2	4.7	33,181,640	380	144**
350+00	1.9	2.4	4.7	31,881,580	173	97
716+00	13.8	4.1	5.4	24,516,150	111	91
830+00	11.9	5.6	6.3	19,140,440	91	91
1310+00	10.1	7.5	8.3	9,994,670	89	89
1782+00	33.8	13.5	13.8	5,823,640	90	90
1930+00	30.1	13.5	13.8	5,798,630	91	91
2230+00	41.9	17.5	18.8	3,254,440	92	92
2660+00	33.8	21.8	21.8	1,438,360	46	39
3330+00	83.1	28.8	46.2	900,810	37	37
3730+00	70.6	30.2	49.5	750,320	34	29
4150+00	76.1	36.8	51.8	730,870	37	37
4630+00	91.8	44.8	63.8	724,400	18	18
4680+00	93.4	70.1	74.7	900,120	14	14
5220+00	102.6	87.8	93.2	913,040	0	15

Notes:
* Time to Initial Wave Arrival - Time from initial spring through dam until the most water surface elevation increases by 1 ft
* Time to Wave Peak - Time from initial spring through dam to maximum flow in main channel
* Peak Discharge - Maximum flow rate
** Maximum Water Elevation - Maximum water surface elevation in channel when maximum flow occurs
** Elevations are in feet above mean sea level. Vertical datum is NGVD 1929.
* Maximum Water Depth - Maximum water depth at lowest point of cross section when maximum flow occurs.
* Inundation boundary condition and limit of inundation study. Peak discharge beyond this station is within the carrying capacity of the Flood Protection System.
** Water depth above Thalweg's Downstream Point NGVD 2210 ft
*** Refer to Dam Breach and Inundation Study for Oroville Dam (Dec. 2005), Appendix I for more information.

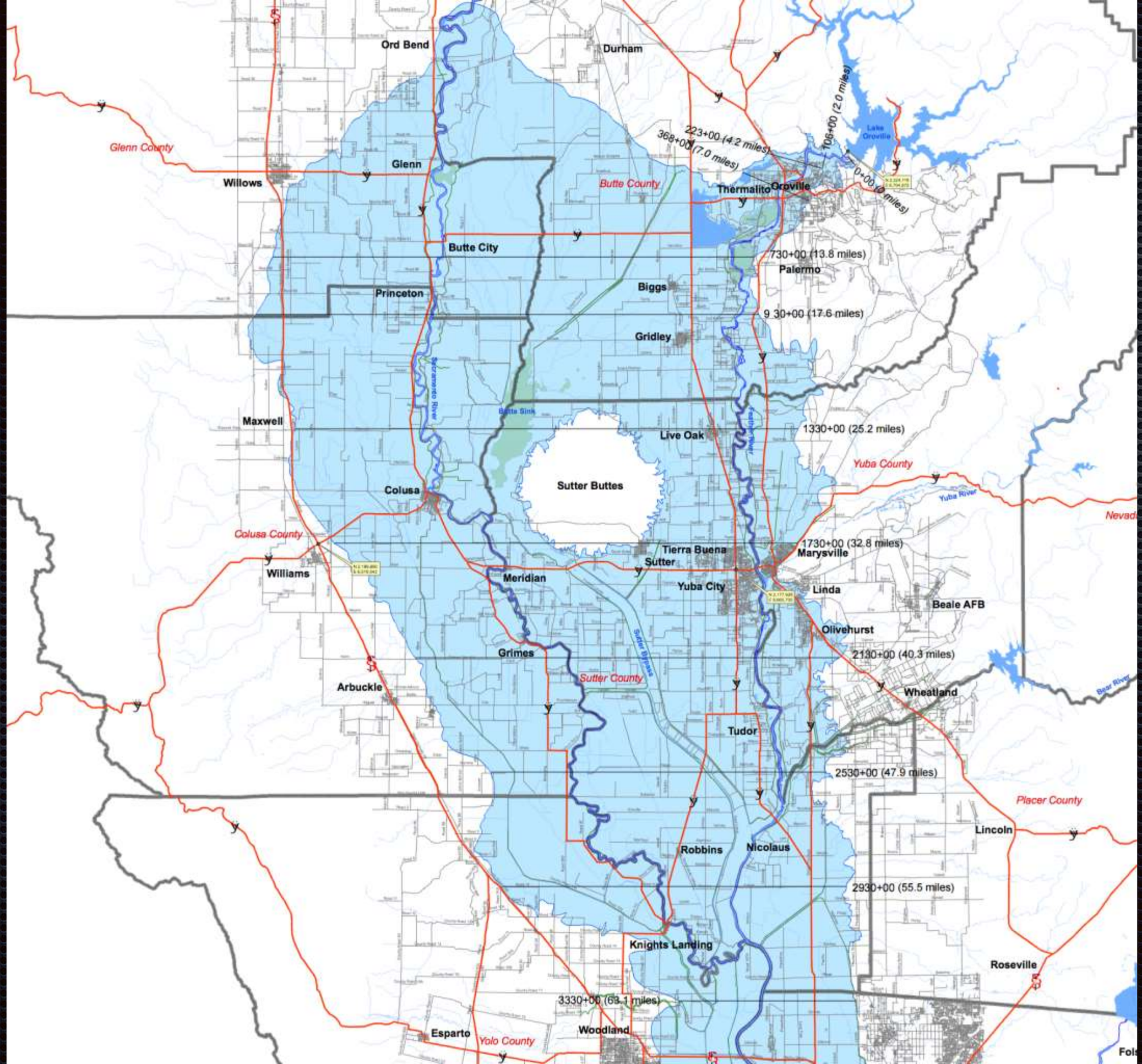
Assumptions:
1. Initial flow conditions - Lake Oroville WSE = 901 ft, spillway gates closed, base inflow and outflow are 1000 cfs.
2. Breach occurs due to piping failure when Lake Oroville WSE = 901 ft.
3. No flow contributions from downstream rivers were included in study (Sacramento, Yuba, Bear, American, etc.).
4. Feather River West Levee assumed to fail allowing flood flow to travel through valley.
5. Flood flow assumed to be contained by Sacramento River Levees and Feather River East Levee.
6. No inundation in offstream areas.

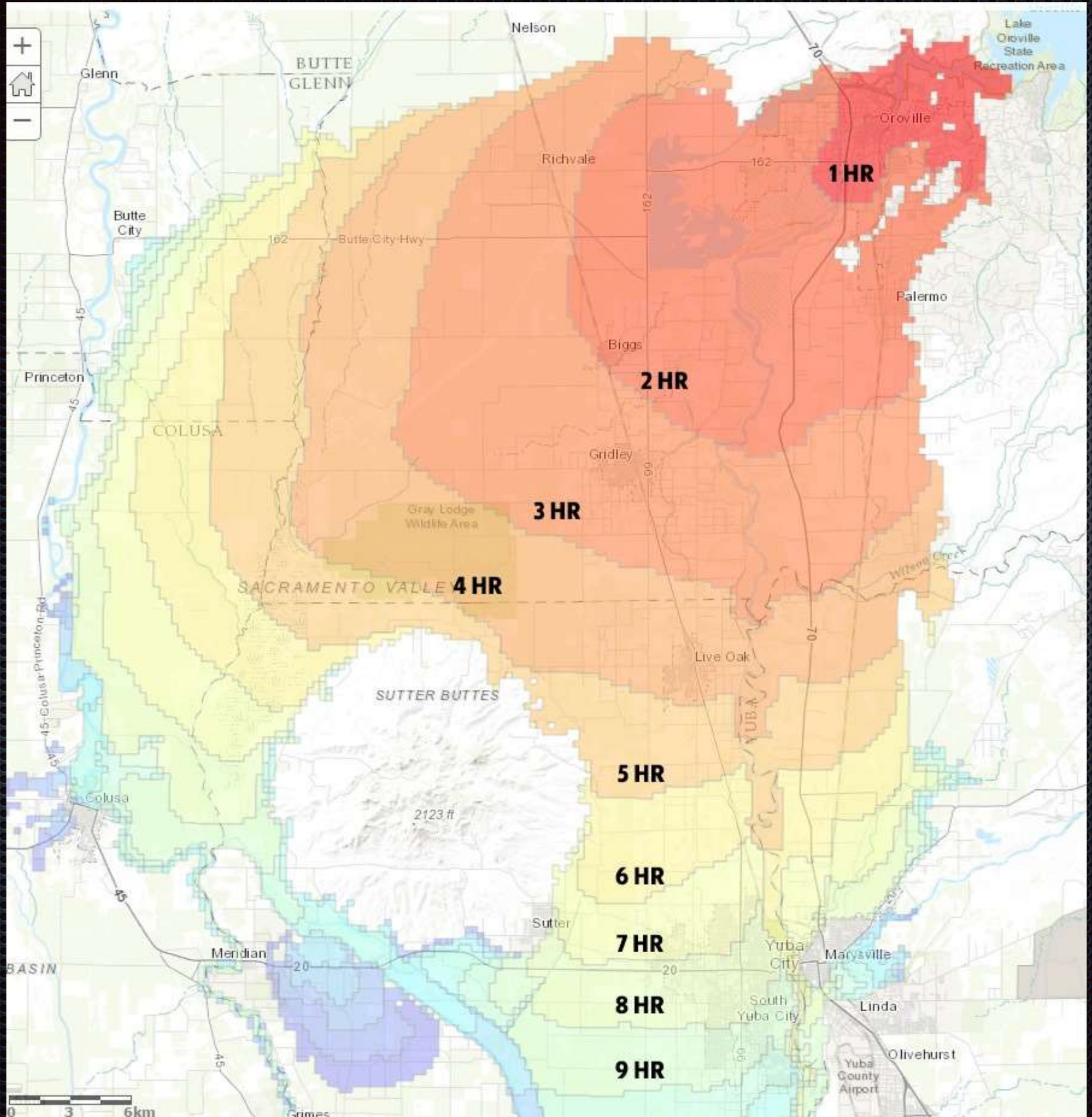
Oroville Dam
Fair Weather Failure
Inundation Map
November 2006 (rev. June 2016)

The inundation areas shown on this map represents an extremely rare event. Publication of this map is not intended to reflect in any way upon the integrity of Oroville Dam. All water depths, travel times, and inundation areas shown on this map are approximate.

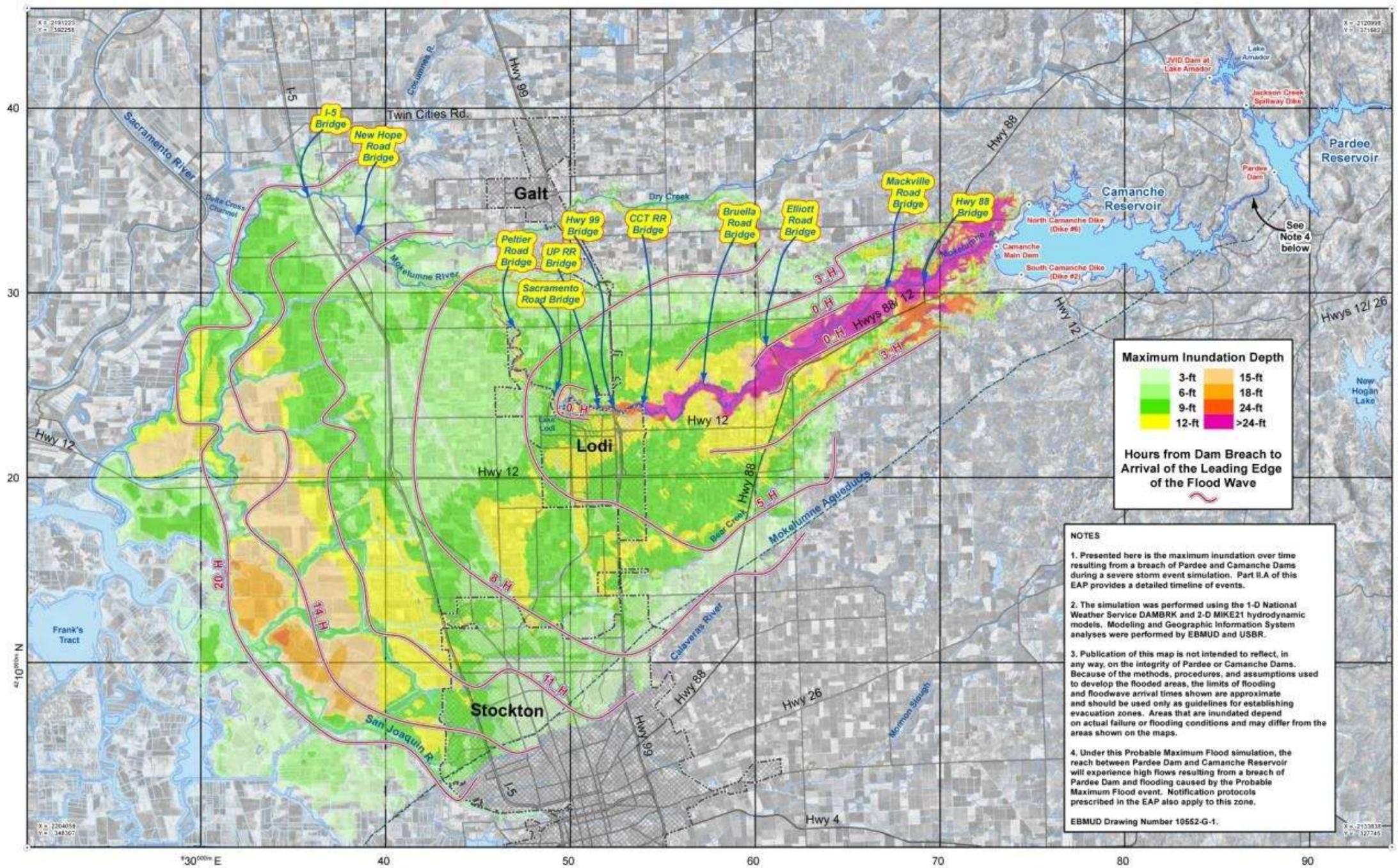
Maps Date Rev. 1 mar
Butte County

CA Department of Water Resources
1416 Ninth Street
Sacramento, CA 95814
(916) 653-5791


Ord Bend
Durham
Glenn County
Willows
Glenn
Butte County
Thermalito
Oroville
Lake Oroville
106+00 (2.0 miles)
223+00 (4.2 miles)
368+00 (7.0 miles)
0+00 (0 miles)
Butte City
730+00 (13.8 miles)
Palermo
Princeton
Biggs
930+00 (17.6 miles)
Gridley
Sacramento River
Butte Sink
Maxwell
Live Oak
1330+00 (25.2 miles)
Feather River
Yuba County
Sutter Buttes
Colusa
Yuba River
Colusa County
1730+00 (32.8 miles)
Tierra Buena
Marysville
Sutter
Williams
Meridian
Yuba City
Linda
Beale AFB
Olivehurst
Grimes
2130+00 (40.3 miles)
Sutter Bypass
Sutter County
Arbuckle
Wheatland
Tudor
2530+00 (47.9 miles)
Placer County
Lincoln
Robbins
Nicolaus
2930+00 (55.5 miles)
Knights Landing
Roseville
3330+00 (63.1 miles)
Esparto
Yolo County
Woodland


Nelson
Glenn
BUTTE
GLENN
Lake
Oroville
State
Recreation Area
Oroville
Richvale
162
1 HR
Butte
City
162
Butte City Hwy
162
Palermo
45
Biggs
Princeton
2 HR
45
COLUSA
Gridley
99
Gray Lodge
Wildlife Area
3 HR
SACRAMENTO VALLE
4 HR
Live Oak
70
SUTTER BUTTES
YUBA
5 HR
45 Colusa Princeton Rd
Colusa
2123 ft
6 HR
45
Sutter
7 HR
Meridian
20
Yuba
City
Marysville
20
BASIN
South
Yuba City
8 HR
Linda
99
Olivehurst
Yuba
County
Airport
9 HR
0
3
6km
Grimes

Another Example Inundation Map



East Bay Municipal Utility District
Lower Mokelumne River Project
FERC Project No. 2916

Figure H.1-1 Inundation Map of Pardee Dam for a Probable Maximum Flood Simulation

Dam Inspection Forms

Notice # _____

Electronic Forms Available Upon Request

East Bay Municipal Utility District
Lower Mokelumne River Project, FERC Project No. 2916
Emergency Action Plan

FERC DAM INCIDENT REPORT FORM

☐ Drill	☐ Information Only	☐ Imminent Failure (About to fail within 24 hours, failing, or failed)	☐ Potential Failure ☐ Rapidly developing (1 day to 1 month) ☐ Slowly developing (longer than 1 month to year)	☐ Non-Failure (Not time sensitive; requires Engineering or Security Assessment)	☐ High Flow (> 5,000 cfs Camanche releases anticipated)

The EBMUD Operator (Pardee Area Control Center, Oakland Control Center, or Water Supply Engineering) has collected the following data and is distributing it to emergency response agencies and District personnel:

Date / Time problem first ☐observed or ☐reported: Date: _____ Time: _____		Date / Time of this Report: Date:_____ Time: _____
Operator Name/Title:	Owner Agency: EBMUD	Telephone Number:
Location of problem: ☐ Camanche Main Dam ☐ Camanche Spillway ☐ North Camanche Dikes ☐ South Camanche Dikes ☐ Pardee Dam ☐ Pardee South Spillway ☐ Jackson Creek Spillway Dam		
	River/Stream:	County:
Latitude:	**Longitude:**	

EBMUD Reservoir data Date: Time:	Pardee Dam (State Dam No.31-004)	Camanche Dam (State Dam No.31-016)
Surface Elevation (ft)		
Storage (ac-ft)		
Max Storage (ac-ft)		
Inflow (cfs)		
Outflow (cfs)		
Release (cfs)		
Spilling?	☐	☐

Situation Description: (physical damage, erosion, sink hole, landslide, leakage, boil, etc.)

Recipient Instructions:

EAP Project 2916 was formally activated: Date: _____, Time:_____

Follow EBMUD on Twitter: @ebmud	For web updates, access:	For additional information contact:

East Bay Municipal Utility District
FERC Project No. 2916, Pardee and Camanche Facilities

Rev. 12/07/2016
CEII Document - CONFIDENTIAL

d-3

Dam Inspection Report

Materials Engineering Section

STRUCTURE NAME _____ DATE & TIME _____
INSPECTED BY _____ WEATHER _____
W.S. ELEV _____

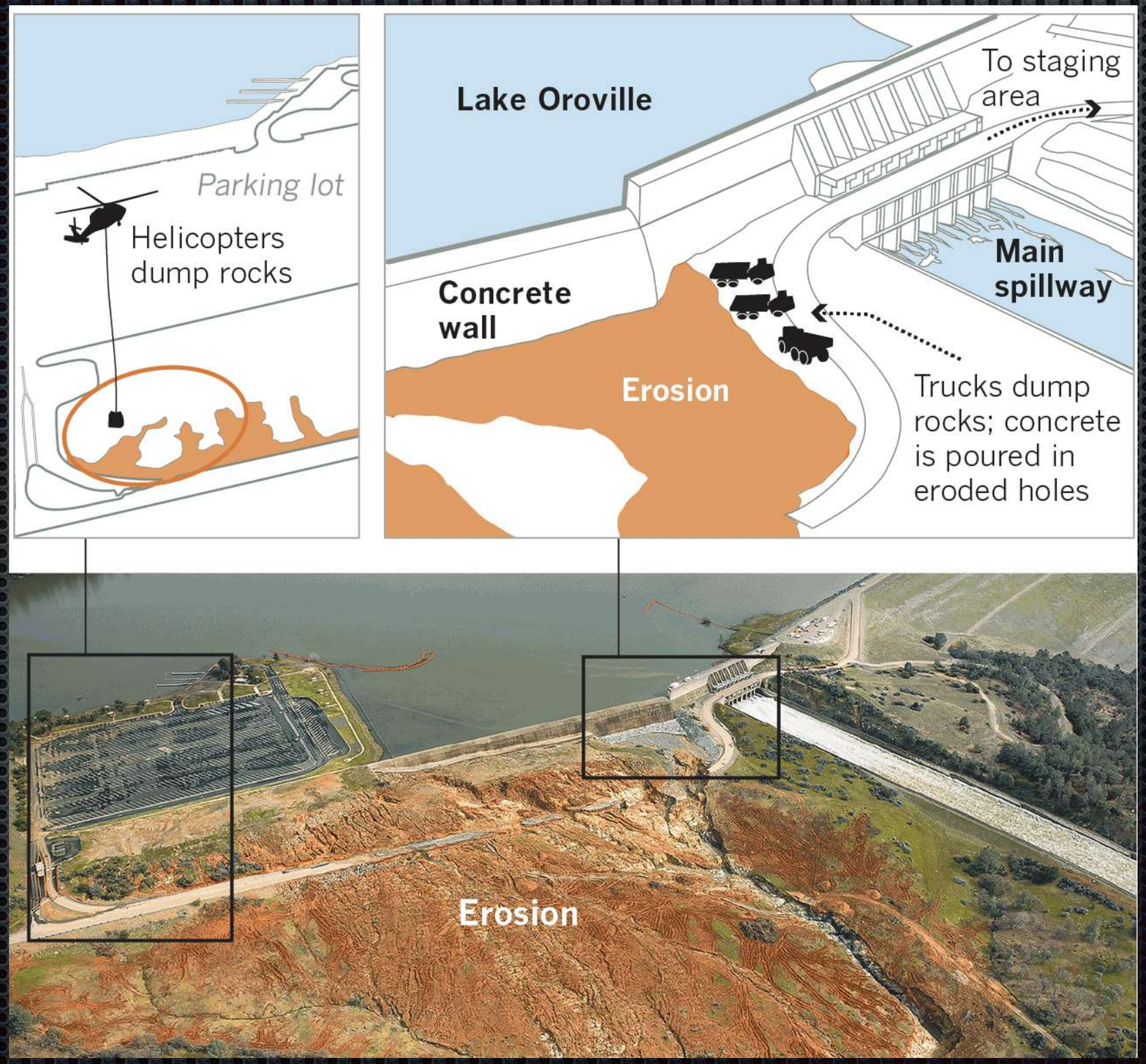
	FEATURE		CONDITIONS OBSERVED	ACTION TAKEN	NOTED
1	CREST	Drainage, structures, cracks, settlement, etc.			
2	UPSTREAM SLOPE	Riprap, facing, erosion, weeds, settlement, cracks, etc.			
3	DOWNSTREAM SLOPE	Drainage, berms clear, seepage, brush, cracks, etc.			
4	DOWNSTREAM TOE	Seepage, drainage, brush, cracks, etc.			
5	SPILLWAY	Cracks, debris, drainage above, weeds, etc.			
6	RIGHT ABUTMENT (Looking Downstream)	Cracks, seepage, brush, etc.			
7	LEFT ABUTMENT (Looking Downstream)	Cracks, seepage, brush, etc.			
8	OUTLET WORKS	Cracks, seepage, maintenance, etc.			
9	STREAM BED DOWNSTREAM	Obstructions, erosion, unusual flow, etc.			
10	INSTRUMENTATION	Accessibility, repair needs, etc.			
11	ACCESS ROADS	Drainage, repair needs, etc.			
12	TUNNELS	Seepage, repair needs, etc.			
13	VALVE PITS	Repair needs, etc.			
14	LEAKAGE				

E-147 2/04 Note: Use reverse side for other features, sketches, remarks, recommendations, etc.

Lake Oroville Facilities

Damage to Main Spillway

Damage to Emergency Spillway



Typical Probable Failure Modes

- Design Flaws
  - Concrete slab thickness
  - Non-continuous, one-layer steel reinforcement
  - Non-effective water barriers
  - Lack of ground anchors
  - Emergency spillway inadequate
- Construction Defects
  - Built on incompetent rock
  - Permeable gravel channels/erosion
- Maintenance Issues
  - Ineffective crack repairs/cavitation
  - Tree roots damaging subgrade drainage pipes

Myths vs Reality

Myth	Reality
2017 flood was much larger than anybody could have predicted.	Peak inflow Feb 2017 was 105K cfs Oroville “standard basis flood” (450-year recurrence) is 440K cfs inflow PMF is 640K cfs
Main spillway flows were large in early Feb 2017.	2017 flow = 60K cfs Design basis = 150K cfs (achieved in 1997)
Losing the use of primary spillway was not reasonably foreseeable or foreseen.	Erosion issue unforeseen, but gates such as those found on the main spillway can and do fail (e.g. Folsom 1995).
Flows over the emergency spillway were higher than foreseen or foreseeable.	Emergency spillway + main spillway are supposed to handle PMF of 640K cfs; peak 2017 flow on emerg spillway was only 13K cfs.
Climate change is to blame for high flows.	Flows were not very high compared to design or prior history.

More Failures....

Folsom Dam 1995
Gate failed open.
Reminder that mechanical devices fail.

Taum Sauk, 2005
0 killed
Designed with no spillway

Thank You